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A final summary of contract work performed during the five year period October 1, 1972 through September 30, 1976 is presented. Results of the contract include significant findings in information systems technology, physiology of exercise, and instrumentation associated with human subject experiments in human physical performance.

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# FINAL REPORT FOR AFOSR CONTRACT
F44620-72-C-0011
Systems Analysis of Physiological Performance Related to
Stresses Such As Those Encountered in High Performance Air Craft

## I. INTRODUCTION

This contract was originally awarded October 1, 1971 for a one-year period terminating September 30, 1972. Subsequently it has been extended for one-year periods four times, with the final termination date September 30, 1976. The contract was an outgrowth of a research grant AFOSR 69-1659, which ended September 30, 1971. Responsibility for certain equipment items purchased under that grant was transferred to this contract. A one-year grant, AFOSR 77-3153, was awarded to permit continuation of key research initiated under the contract. This grant will terminate September 30, 1977.

The initial principal investigator of contract AFOSR 72-C-0011 was Loren D. Carlson, Ph.D., who also initiated the research under grant AFOSR 69-1659. Dr. Carlson became terminally ill late in 1971 and transferred the responsibilities of principal investigator to R.F. Walters when it became clear that he would not be able to fulfill these responsibilities. Dr. Carlson continued to provide advice and assistance on the contract until his death in December, 1972.

Annual reports of the first four have been submitted following the completion of each of the first four years' investigations. These reports describe in detail the research accomplished during those time periods. This final summary report details the results of research accomplished during the last twelve month period of the contract and summarizes the principal accomplishments for the entire contract.

## II. RESEARCH GOALS

A. Improvements in techniques of measuring and storing observations of physiological responses of subjects undergoing a variety of training and conditioning regimens and exercising under a variety of environmental stresses.

B. Application of these techniques to basic research in human performance physiology as it relates to performance of Air Force tasks.

C. Development of cooperative arrangements between institutions with related research interests to facilitate progress in items A and B above.

## III. RESEARCH OBJECTIVES

Within the framework of the goals stated above, a number of specific research projects were undertaken. These projects are listed below.

### A. Development of Information Systems Support

1. Conversion of earlier bibliographic support system to new campus equipment, and distribution of results to interested research institutions.

2. Development of interactive Data Storage and Analysis Package (DSAP) and transfer of program to U.S. Air Force Academy.

3. Development of techniques for remote use of data acquisition equipment.

4. Duplication of data acquisition system at U.S. Air Force Academy, using new (1976) computer technology.

5. Refinement of Human Performance Model and distribution of model to interested research institutions.

6. Development of software support packages for data acquisition system.

7. Development of improved measurement techniques for observation of blood volume.

8. Development of techniques for measurement of blood pressure during exercise.

9. Application of improved blood chemistry methods for measuring catecholamines for exercising subjects.

10. Development of remote data collection techniques for free-moving subjects exercising in an open air environment.

11. Refinement of R-wave detection system initially developed by NASA and loaned to U.C. Davis.

12. Development of computer-controlled treadmill and bicycle ergometer exercising equipment.

13. Development of techniques for data transfer between data acquisition system and large central computer facility.

14. Evaluation of several techniques for measurement of skin temperature from surface of exercising subjects in laboratory and open air environments.

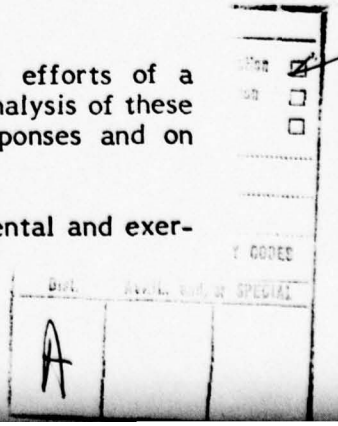
15. Investigation of different computer languages for information systems aspect of project.

16. Development of time-series analysis technique for the study of sinusoidally varying physiological parameters for autocorrelation and phase analysis.

## B. Physiological Investigations

1. Developent of Data pool describing maximal exercise efforts of a spectrum of male subjects from 18 to 65 years image. Analysis of these data in terms of effects of conditioning on aging responses and on tolerance limits with advancing age.

2. Investigation of thermoregulatory responses to environmental and exercise stress.



3. Study of effects of conditioning at altitude on performance at sea level.

4. Dynamic responses of cardiovascular system to sinusoidally varying work loads.

5. Comparison of human performance responses of comparable age groups of military and non-military subjects.

6. Development of longitudinal information file on USAFA cadets, with emphasis on analysis of changes effected at entry to the Academy and longitudinal changes throughout course of stay at Academy. Continuation of follow-on studies into career positions if possible.

7. Blood volume studies of subjects of wide range of fitness characteristics.

8. Development of single, multistage branching treadmill exercise evaluation protocol suitable for testing subjects from post-coronary bypass patients to highly trained long distance runners.

9. $P_{50}$ responses to acute exercise.

10. Application of a physiological profile to assess physical performance capabilities and limitations of Air Force personnel.

11. Effects of various types of conditioning on $G_z$ tolerance.

12. Changes in fibrinylitic activity, Factor VIII and hematologic values during and after maximal exercise.

13. Neurogenic factors involved in regulation of respiration during sinusoidally varying workloads.

14. Combined effects of breathing resistance and hyperoxia on aerobic work tolerance.

15. Oxygen utilization of peripheral tissue (a companion study supported through AFOSR-provided equipment).

C. **Development of Cooperative Arrangements with other Air Force Related Research Institutions**

1. Collaborative studies with USAFA: performance tests at both sites, joint studies of Air Force and civilian personnel, expansion of physiological testing facilities and computer hardware and software for studies at USAFA, installation of computer programs at central USAFA computer, training of USAFA personnel in case of delivered hardware and software.

2. Collaborative studies with Brooks Air Force Base and School of Aerospace Medicine: joint studies of model of dynamic cardiovascular response to exercise; collaborative investigation of effects of conditioning on acceleration performance; use of UCD analysis programs to study SAM data.

3. Collaborative studies with Wright Paterson/AMRL laboratories: thermoregulatory investigations; consultation on use of microprocessor technology in information support systems; evaluation of human performance models.

4. Collaborative studies with AFOSR-sponsored research institutions: Universities of Kentucky, Indiana, California at Santa Barbara and Los Angeles; Mayo Clinic.

5. Development of procedure for studying air force personnel on active duty.

## IV. RESEARCH RESULTS

Considerable progress has been made on most of the items listed above. The specific results are outlined below. Specific products such as publications, reports and computer programs are separately itemized in subsequent sections.

### A. Information Systems Support

#### 1. Bibliographic System

Microfiche copies of bibliographic materials were sent to AFOSR, AMRL, AMD, USAFA, and Goddard Space Center. These reprints were accompanied with a summary listing of the articles in each of the three libraries maintained: Human performance, energy exchange and peripheral circulation. Searches were conducted on request for various institutions uring the first two years of the contract period. The computer program supporting this effort was sent to Wright Patterson AFB as well as to several other interested research groups not connected with the Air Force. A copy is available on request at UCD. The program comes in interactive as well as batch versions.

#### 2. Development of Interactive Data Storage and Analysis Package

Two generations of this system were developed during the contract period. The first version was installed at USAFA, where it was demonstrated during the Research Review meetings of 1973, held at USAFA. A recent revision of the package is documented by the manual that accompanies this report. This package is currently under evaluation by USAFA computer center personnel for possible use at that institution. A copy is available at UCD for duplication or transmittal upon request.

#### 3. Development of Techniques for Remote Use of Data Acquisition Equipment

A great deal of work has gone on in this area. Remote use of IRIG telemetry was demonstrated early in the project, using sites across campus as well as remotely through telephone lines. Direct transmission of data for short distances through twisted pairs of wires was also demonstrated. More recently, however, a number of experiments have

been conducted involving the transportation of testing equipment to remote sites. Two such studies, one at USAFA and the other at Nellis AFB, were conducted in 1975. A third set of studies was conducted at USAFA in May 1976, and the equipment left at USAFA to permit its continued use until permanent equipment could be installed.

Development of local telemetry of data has been initiated, with some successful results to date. Completion of this portion of the research is scheduled for the continuation grant currently under way.

4. Duplication of Data Acquisition System at USAFA

An extensive evalûation was undertaken to define systems of computer hardware capable of supporting physiological investigations at the Academy. Every effort was made to design a system that would be inexpensive and yet capable of all studies currently supported at Davis. The resulting equipment specification called for some items to be bought in kit form, some components to be purchased complete, and some components to be constructed here. Purchase of this equipment is nearly complete at this time. Hardware has been received enabling the system to be programmed and tested. Final completion of the system is anticipated for January, 1977. Programming is largely complete at this time, and the documentation is in draft form.

The system currently on loan to the Academy has been used extensively during the past six months for a variety of studies, including the first annual follow-on measurements of the cadet performance tests initiated in the summer, 1975. This sytem will be left at the Academy until the new configuration is installed early in 1977.

5. Refinement of Human Performance Model and Distribution of Model to Interested Research Institutions

The human performance model underwent major revision during the early years of this contract. A revised version was completed in 1973, and a major reference published in January, 1974. Since that time, the model has undergone only minor revisions.

The interest generated by this model has been extensive. Reprint requests continue to arrive, nearly three years after appearance of the key article. Requests for copies of the computer program have been received from research and educational institutions throughout the country and internationally. A number of versions of the model have been developed on computers other than the B6700 used at Davis. One such version was developed at the University of Indiana under AFOSR support, and the resulting program sent to Wright Patteson AFB. Other versions have been shipped to a number of institutions, including USAFA.

Interest in extensive review of the physiological systems described in this model, with a goal of developing more completely the predictive capabilities of the model, were deferred from the summer of 1974 and have not been rescheduled. No funding for model improvement was requested since the 1973-74 time period.

6. Development of Software Support Packages for Data Acquisition System

An extensive collection of systems and applications programs has been developed for the Raytheon computer that serves as the data acquisition system for the Davis campus laboratory and, temporarily, for the system on loan at USAFA. This software was documented in a pair of reference manuals that were distributed to key personnel during the 1974-75 contract period. copies of the manual were also sent to AFOSR at that time. Additional copies are available on request.

This package of supporting software has undergone only minor revisions since that time. Updated software manuals for this system as well as for the new system to be installed at USAFA will be completed during the 1976-77 grant period.

7. Measurement of Cardiac Output by Electrical Impedance

The routine measurement of stroke volume and the calculation of cardiac output are fundamental to a number of the investigations completed over the past five years. A method was needed to incorporate this measurement to a relatively large number of subjects routinely, in a nonclinical setting and that it be noninvasive. The existing options were those of carbon dioxide to nitrous oxide rebreathing either single or multiple breath and the one we chose, electrical impedance cardiography.

Although the method and instrument had been developed, its status as a valid method of measuring stroke volume remained unresolved. The senior investigator, Kubicek, who developed the methodology provided us with a personal demonstration seminar. It remained for us to explore its validity against the conventional indocyannine green method for different postures and at different loads of work. This work was completed with the cooperation of Dr. Robert Zelis in the University of California, Davis, Medical School. The data show correlations of .81 and .90 for stroke volumes for different postures and for different workloads, respectively. Cardiac outputs showed correlations of .84 and .88 between the two methods. We concluded that if posture is fixed and the workload on a bicycle ergometer is standardized on a physiological basis (% $\dot{V}O_2$ max), the noninvasive impedance cardiographic method provides a very accurate estimation of the changes in cardiac output with work. This study is in the final stages of write-up for publication, the title is cited under manuscripts in preparation.

8. Development of Techniques for Measurement of Blood Pressure during Exercise

The need for serial measurements of blood pressure during exercise continues to resist easy solution. As a parameter to assess circulatory function, it occupies the same priority as heart rate. The noise and movement artifacts generated during exercise create conditions which are the basis of the technical difficulty. Efforts in the Human Performance Laboratory at the University of California, Davis have narrowed the options to the use of a Doppler ultrasound and Korotkoff measurements of blood pressure. This method has been used successfully in a manual mode but the ultimate objective is to incorporate these measurements within the existing on-line data acquisition system presently operating in the HPL. This effort is in the preliminary stages and will be given priority during the next year.

9. Application of Improved Blood Chemistry Methods for Measuring Cathecholamines in Exercising Subjects

The routine measurement of urinary and plasma cathecholamines is difficult at best and, until recent microtechniques were developed, required a large volume of blood making multiple or serial analysis impossible. Our interest in assessing the physical stress experienced by men engaged in heavy exercise induced directly by a physical work task such as flying high speed aircraft or engaged in PT programs in preparation for stressful environments, directed our efforts to employing these measurements. Initial and essential help was obtained through the cooperation of the Environmental Institute at Santa Barbara. Subsequent help was received from other U.C. sources. The procedure developed was a modification of the one developed at Santa Barbara for non-adrenaline, adrenalin and free cathecholamines and employed a standard Bio Rad laboratory kit. The blood volume needed was 10 ml and the procedural tactic was to work with a very dilute aliquot to increase the sensitivity of the column exchange reaction. This approach proved successful in the hands of Dr. Henry Stinnett but upon later repetition failed to provide the same sensitivity necessary to measure the physiological levels observed in plasma. Work is continuing in our laboratory to resolve this method for future measurement on a routine basis. It is premature at this point to present any of these substantial developmental efforts for publication.

10. Development of Remote Data Collection Techniques

During the course of the investigations conducted at UC Davis and elsewhere, it has become apparent that certain studies, particularly those relating to thermoregulation, require investigation in an unrestricted, open-air environment. The contract research has had as one objective the development of telemetry methods that will permit exercising subjects to carry light-weight sensors and a transmitter for these types of investigations. To date, a single channel system has been demonstrated effective, and several types of multichannel (multiplexed signals from several sources) devices have been built and tested. Further

refinement is needed, however, and these studies have been extended into the grant period running from October 1, 1976 through September 30, 1977. The final design will be described in the summary for that investigation period.

11. The collection of heart rate data, particularly during exercises generating considerable electromyographical artifact, has been aided significantly by the use of a NASA supplied R-wave detector.

The original circuitry is in constant use in the Human Performance Lab at U.C. Davis while a functional duplicate, fabricated at Davis with permission from NASA, allows concurrent data collection with the Raytheon 703 system loaned to the Air Force Academy.

A second generation hybrid R-wave detector has been designed for use in the new microcomputer data acquisition system. This system will incorporate some design advancements over the current NASA system.

12. Interfaces enabling computer control of treadmill and bicycle ergometer workloads were developed in order to create reproducible complex workload forcing functions. All workloads are software-defined by the Raytheon 703 during real-time data acquisition, for both open- and closed-loop experimental protocols.

Treadmill speed and elevation are detected by a phase locked loop configuration and an optically encoded elevation reference, respectively.

Workload of the electronically braked bicycle ergometer is controlled by voltages from an anlog-to-digital convertor and by currents switched in a resistive ladder network controlled by the computer.

The capability of performing programmed or closed-loop exercise studies opens the door for a number of highly significant studies, including investigation of optimal recovery regimens for coronary patients, elimination of the "perceived effort" problem as a factor in exercise, and other studies of dynamic responses of the physiological system.

13. Data Communication

Techniques for data transfer between the DAS and central facility proved necessary because only the central computer was capable of handling the large amounts of data and the sophisticated data analysis programs. Data is sent serially over a communication link or manually transported on compatible digital type in a format suitable for use by the analysis and filing system. Files may be selected on the DAS from several tapes and edited onto one tape for data transfer. The software for this communication system has been fully documented and is available for use elsewhere.

14. Evaluation of Several Techniques for Measurement of Skin Temperature from Surface of Exercising Subjects in Laboratory and Open Air Environments

The work in this area has included evaluation of Aga thermovision infrared camera techniques for measurement of skin temperature, use of sensors provided by researchers at the University of Indiana, and investigation of several techniques developed or adapted at Davis. A detailed summary of the results obtained during the current contract year is provided in Appendix I of this report.

15. Investigation of Language Support Systems

A number of characteristics of interactive computing have been investigated in conjunction with this project, including not only the development of a new data analysis package, but also the investigation of the feasibility of using a defined interpretive language for editing data. The MUMPS (Massachusetts General Hospital's Utility Multi-Programming System) interpreter was implemented on the Burroughs 6700 computer in 1973, and studies were conducted to investigate its relation to the data analysis program. The complexity of interface between the two language systems has indicated that the two languages should probably be maintained distinct, and subsequent designs of the analysis package were developed independent of MUMPS. The experience gained from this study has been valuable in suggesting different file structures for the data package, however, and an independent project involving MUMPS has been carried on with other support.

16. A biomedical computer program for time series analysis was modified and adapted to analyze treadmill and other data produced under sinusoidally varying workloads. The analysis program provided phase lag and correlation information in addition to time series plots of the data. Data with workload periods ranging from .5 minute to 15 minutes were analyzed for heart rate and ventilation volume phase information.

## B. Physiological Investigations

1. In our 1972 paper (cf. Adams, et al., 1972 Clin. Sci.), we noted a near rectilinear decrease in treadmill walk time and maximal oxygen uptake ($\dot{V}O_2$ max) with advancing age in healthy sedentary middle-aged males. Heart rate (HR) and pulmonary ventilation (VE) at maximum tolerable effort also declined with age. There were no age related differences in $\dot{V}O_2$, VE and HR during submaximal work, and it was concluded that the decline in maximum performance with age was not due to differences in the efficiency of aerobic energy utilization, but rather, to factors limiting energy production. Comparison of the coronary artery disease patients' treadmill performance and physiological response to similar age, sedentary normal men indicated the following: (1) Most patients

trained after myocardial infarction can achieve similar performance levels of normal, sedentary subjects, but some do not exhibit a classic training effect, probably due to residual myocardial dysfunction; and (2) successful coronary artery bypass surgery does not entirely normalize work performance, metabolic or hemodynamic function, although angina and electrocardiographic changes can be reduced.

2. In our collaborative work with Dr. James Veghte, preliminary analysis of IRA thermal scan and taped thermistor measurements, taken before and during running indoors on a treadmill and outdoors during a road run, demonstrated altered skin temperature and cutaneous blood flow from rest was best reflected by IRA thermal scanning. Similar comparisons during isometric and isotonic leg exercise also revealed the inadequacy of the taped thermistor in reflecting accurate transient changes in skin temperature. These preliminary analyses of our observations and those of others have established a basis for regional skin temperature variation and peripheral blood flow changes in man exercising in a variety of modes in ambient temperatures ranging from cool to hot. However, the modifying influence of humidity, air flow and solar radiation had not been systematically studied.

During this past summer, the effects of forced convection and solar radiation on the ambient dry bulb ($T_{db}$), mean skin temperature ($T_s$) relationship was studied in three distance runners while running and cycling (cf. Adams, 1976 Progress Report). Using a specially devised plastic ring thermistor applicator harness, seven skin temperatures and rectal temperature were monitored sequentially at 3-4 sec intervals each minute during treadmill runs of 11.1 km at 254 and 293 m/min in cool, moderate and warm $T_{db}$, with and without airflow equivalent to the runner's speed. Similar data were collected during outdoor runs and bicycle rides both in direct solar radiation and after sunset. It was concluded that reduced convective and evaporative cooling of indoor runs without airflow and direct solar radiation in outdoor runs significantly increased $T_s$, and that the increased heat strain in these warm $T_{db}$ conditions was sufficient to elevate $T_{re}$ to levels suggesting impending risk of heat injury.

There are situations in which direct continuous measurement of skin temperature, as with our plastic ring thermistor applicator harness, is not practical. Thus, we plan to develop a biotelemetry capability, which will enable us to include pertinentheat exchange data in our analyses of limiting factors in human performance.

3. In our 1971 paper (cf. Dill & Adams, JAP), we concluded that discrepancies in previous research findings regarding sea level endurance performance after moderate altitude exposure could be attributed to the complexity of interrelated factors, such as state of training, the altitude, length of altitude sojourn, and differences in training intensities while at altitude. Since a control group had not been used in prior studies of trained runners, we sought to resolve some of the uncertainty attendant to the problem by employing this technique. The purpose of our 1973 experiment (cf. Adams, et al., 1975), was to determine if there is a potentiating performance effect at sea level (SL) attributable to physiological adjustments from training for 21 days at 2,300-m altitude, as compared to training at equivalent intensity near sea level. Group 1 trained for 3 weeks at Davis, running 19.3 km/day at 75% of SL $\dot{V}O_2$ max, while Group 2 trained an equivalent distance at the same relative intensity at the US Air Force Academy (AFA), 2,3000 meters in altitude. The groups then exchanged sites and followed a training program of similar intensity to the group preceding it for an additional 3 weeks. Periodic near exhaustive $\dot{V}O_2$ max treadmill tests and 2-mile competitive time trials were completed. Initial 2-mile times at the AFA were 7.2% slower than SL control. Both groups demonstrated improved performance in the second trial at the AFA ($\bar{x}$ = 2.0%), but mean postaltitude performance was unchanged from SL control. $\dot{V}O_2$ max at the AFA was reduced initially 17.4% from SL control, but increased 2.6% after 20 days. However, postaltitude $\dot{V}O_2$ max was 2.8% below SL control. It was concluded that there is no potentiating effect of hard endurance training at 2,300-m over equivalently severe SL training on SL $\dot{V}O_2$ max or 2-mile performance time in already well conditioned middle-distance runners.

Most investigators report that the basal metabolic rate (BMR) increases during the first days at altitude. As a corollary to our 1971 investigation (Dill & Adams), we sought to determine if highly trained distance runners' BMR responded differently at altitude than that of untrained laboratory personnel (cf. Burris, et al., 1974 Human Biol.). Our observations indicated no significant differences between these two groups, and that the large increase in BMR, as well as smaller increases in HR and blood pressure were transitory, returning to, or almost to, SL

values within 2 to 3 weeks. Only VE, because of reduced arterial $O_2$ saturation, remained high through the altitude sojurn.

4. Dynamic Responses of Cardiorespiratory System to Sinusoidally Varying Workloads

Following an extensive development of the on-line data acquisition system in the Human Performance Laboratory and the associated development of physiological instrumentation to measure physiological responses during standardized bouts of work, we were able to pose some fundamental questions concerned with the dynamics of the cardiorespiratory system during exercise. These questions included modeling both steady-state and dynamic responses to exercise. The results are reported in an abstract, paper, and thesis attached.

The principal findings include the following: 1) the steady-state model proved to be an acceptable first approximation, but the inclusion of transient characteristics are essential in describing the overall system adjustment to exercise, 2) the gain and phase relationships reveal a probable first order system with a six-minute time constant, 3) the cardiorespiratory response to dynamic exercise described by HR, $\dot{Q}$ and $\dot{V}O_2$ is linear up to 70% of $\dot{V}O_2$ max, 4) as the rate of change of workload increases the longer time constants in HR and $\dot{V}O_2$ response dominate, and thus slow the response, and 5) stroke volume does not play a significant role in the cardiorespiratory response to dynamic exercise at work rates up to 70% of $\dot{V}O_2$ max.

5. With the advent of the new generation of fighter aircraft, pilots are now routinely exposed to high levels of sustained $+G_z$ forces. They commonly complain of fatigue and a non-specific stress after relatively short periods of intense simulated tactical flying. The question of physical condition and age as it might affect their capacities to absorb this routine high $+G_z$ stress seem relevant. To this end we set out to compare a group of non-flyers, very fit and with average fitness, through the age span of the career military pilot. The following are some of the chief findings of this study not yet completely analyzed.

Of the 17 pilots measured on a standardized exercise stress test at Nellis Air Force Base, (they represented a mix of pilot assignments other than fighter aircraft) the pilots under 35 had a higher $O_2$ capacity than the older pilots but both groups were below the average for their civilian

counterparts. The civilian trained group for both age groups had a significantly greater $O_2$ capacity ~ 30 ml/kg min and 20 ml/kg min for the under and over 35-year-age bracket, respectively. Blood measurements completed on the civilian groups show no age or fitness differences for hematocrit, venous pH, or $pCO_2$ at rest but do reveal a fitness difference regardless of age for all of the above parameters including blood lactate. The younger men had a significantly higher RBC $p50_{iv}$ than the older men and also the nontrained younger men. The plasma catecholamines were significantly higher in the older men than the younger men. Also, the increase following exercise is less marked in the trained. One conclusion is that training aids the catabolism of the catecholamines and may provide a reduced stress imposed by the physical work of high $+G_z$ forces experienced in flying.

6. A study of the immediate and intermediate effects of the PT programs at the USAFA on cadets' physical and physiological development was initiated in the summer of 1975. Since the career officer represents a substantial investment, and is expected to master flying skills requiring a high degree of physical stress or serve as an executive administrator with its incumbent stress, it seemed of no small concern to determine the impact of the summer PT program on their physiological adjustment to the altitude and military routine of the Academy and more generally to the four-year program at the Academy. Subsequently, this data base would serve as a reference to their physical and physiological capabilities throughout their military career. This is an ongoing program and only the immediate phase is completed.

The sample of cadets measured were found to be above average in fitness compared to comparable age college students. Following five weeks of summer training, the cadets did not change weight but did lose a significant amount of body fat. Their blood hematocrit increased significantly but there was no change in their $O_2$ capacity. (Incidentally, this observation was seen again this past year in the male cadets but the female improved significantly). The lactic acid levels increased significantly following exercise along with the duration of their walk on the treadmill. This suggests an increase in their anaerobic tolerance. It suggests that the emphasis in PT programs is anaerobic or power activities rather than endurance or aerobic activities. This may be entirely appropriate, given the recent evidence of Captain Lewis Epperson who has studied the effects of exercise composition on $+G_z$ tolerance. The findings of Jim Davis in his thesis "The Effect of

Endurance Training on the Anaerobic Threshold of College Age Males" provides important correlative information related to the above observations.

7. A comparison between the blood volume (BV), and its components, of 12 highly trained middle distance runners and 48 non-athletic males of similar age was reported in 1974 (cf. Dill, et al). Blood volume in relation to body weight (BW) was 21% greater in the runners than in the non-athletes. Cell volume, PV and total Hb, all in relation to BW, were greater in the runners by 18, 24, and 16%, respectively. Consistent with the difference in PV and in CV, Hb concentration was 4% lower in the runners. Our study was not specifically designed to identify quantitative discrepancies in reported BV and its components, but our results do suggest three plausible explanations: (1) Failure to assess likely differences in body composition, particularly percent of BW as fat in the subjects studied; (2) Possible measurement differences in the various methods utilized; and (3) The frequent lack of quantitative descriptions of the subjects studied, especially in terms of $\dot{V}O_2$ max. Furthermore, although a close correlation between Hb and $\dot{V}O_2$ max in normal young men and women has been observed previously, we noted similar slopes in the regression lines of $\dot{V}O_2$ max on total Hb content for young untrained males, trained female swimmers and highly trained middle-distance runners, but the intercepts were strikingly different. Studies designed to elucidate these apparent discrepancies have been proposed and are currently being carried out.

8. The Branching Multistage Treadmill Test (see Xeroxed protocol) was first utilized in 1974 to examine the submaximal cardiorespiratory response and maximal working capacity of 148 healthy, normalmales, aged 20 to 81.5 years. Their general activity pattern varied with age and inclination, but none had participated in a systematic physical training regimen within two months of testing. Selected anthropometric parameters, smoking and current physical activity history were recorded. Throughout the treadmill test, a cotninuous expiratory sample was drawn into a Medspect mass spectrometer, Model MS-8, and the output voltages for FE $N_2$, FE $O_2$, and FE $CO_2$, were fed directly into a Raytheon

computer, Model 703. Heart rate was determined by an averaged time interval of consecutive EKG R-wave interrupts, with running average of HR, $\dot{V}E_1$ RQ and $\dot{V}O_2$ for the previous minute printed on a teletype every 15 sec. All data were stored on mag tape for subsequent reduction and analysis. Preliminary analysis of the maximal cardiorespiratory data showed the expected age related decline (from mean age of 24 to 75): HR max - from 194 to 146 beats/min; $\dot{V}O_2$ max - from 46.7 to 26 ml/min kg; $O_2$ pulse - from 18.1 to 13.2 ml/beat; in VE max - from 122.7 to 65.6 L/min, BTPS; RQ max - from 1.08 to 0.93; and in Ventilatory Equivalent -from 3.02 to 2.74 L VE per 100 ml $O_2$.

Preliminary analysis of submaximal cardiorespiratory responses indicate that the 2 minute stages are of sufficient length to effect a near steady-state metabolic response, as evidenced by a plateauing of $\dot{V}O_2$ during the last 30 sec. at each workload. Comparison of submaximal cardiorespiratory responses of the entire 148 subject is difficult because of the different workload increments entailed in each branch. It is planned to attenuate this problem by reducing the size of the age related comparison to those subjects who terminated in Branch 3 (which included subjects ranging in age from 23-75 years). This comparison will permit us to determine if the reduced maximum performance capacity with advancing age is due, in part, to possible cardiorespiratory inefficiency evidenced in submaximal work. Similar comparisons between smokers and non-smokers, middle-aged males active in endurance running programs and similar age sedentary, normal males are planned.

The branching Multistage Test protocol has been used to test patients with coronary artery disease (unpublished observations) and yielded a mean $\dot{V}O_2$ max of 73.5 ml/min/kg for a group of highly trained middle-distance runners. The latter value closely approximates the measured $\dot{V}O_2$ max using a faster running previously reported (Adams, et al., 1975).

9. <u>The Physiological Significance of 2-3 Diphosphoglycerate (2-3 DPG) Levels in vivo RBC $O_2$ Dissociation Responses to Stressors in Dogs and Humans.</u>

It has been suggested that altitude changes may be part of an intracellular adaptation of initial serum hypoxia, hypocapnia, and

alkalosis transitionally experienced during adaptation. Daily excretion of norepinephrine has been shown to increase in humans who have ascended to moderate altitude while epinephrine remained relatively unchanged. Resting plasma norepinephrine levels in endurance trained athletes were found to be nearly three times those of an untrained comparable age, while epinephrine levels were essentially similar.

These observations led to the related study involving pilots at Nellis Air Force Base. The specific question in the present study was to determine if canine and human RBC 2-3 DPG levels are responsive to hypoxia, hyperoxia, and the administration of epinephrine and norepinephrine. The dog phase of the experiment with its focus on arterial and venous blood levels and the administration of cathecholamines preceded the human exercise experiments. Results showed highly significant changes in venous RBC 2,3 DPG correlated to the $P_{50(iv)}$ estimates during hypoxia and norepinephrine administration. Three other factors were changed in a similar manner during hypoxia and norepinephrine administration, viz., systemic arterial pressure, pulmonary arterial pressure and the mean corpuscular hemoglobin concentration. It would appear that the heavy muscular efforts imposed during high $+G_z$ and hypoxia may result in a significant output of norepinephrine and associated change in the levels of 2-3 DPG. Consequently, a program to train for this response may prove beneficial. This study is in the final stages of preparation for publication.

10. Application of a Physiological Profile to Assess Physical Performance Capabilities and Limitations of Air Force Personnel

This study has not been completed and in fact, will be a synthesis of information gathered from studies #5, 6, 11, and 12. Given the affects of cadet training, age and fitness changes of career officers in the Air Force, and the specificity of exercise training either by weight training or endurance running on $+G_z$ tolerance, we propose to develop a valid test battery that can be applied by technical personnel periodically throughout the service tenure of career officers. This is much like the current strategy used in government and industry to assess the physical qualifications of applicants and subsequently to determine fitness for the job. The test battery - Physiological Profile - would be simplified to permit economic application under most duty stations. Related studies currently in progress and expected to lend valuable insight in the eventual construction of the physiological profile are theses in various stages of completion by Judy Flohr, Joanie Smith and Steve Vignau.

11. The Effect of Physical Conditioning on $+G_z$ Tolerance

The study, entitled above, was conducted at the Brooks Air Force Base Aerospace Laboratory and was a cooperative effort between the University of California, Davis, and Brooks in support of Captain Lewis Epperson's Ph.D. dissertation. The project focused on the specific contribution made by exercise training to $+G_z$ tolerance. Earlier studies, viz., 3, 4, 5, and 9 provided substantial insight into the physiological response of career aged men in varying states of physical condition; in addition, the dynamics of cardiorespiratory blood $O_2$ transport have been studied as underlying functions of stress tolerance.

Two exercise programs were studied, one designed to emphasize high intensity-low duration activity such as weight lifting; the other to emphasize high duration-moderate intensity such as running. A period of orientation instruction was given to 30 Lackland trainees on treadmill running, weight training, and particularly centrifugation. Measurements were made prior to, and periodically throughout the training program. Partially completed results reveal that the weight lifters significantly improved their $+G_z$ tolerance to $+G_z$ ranges between 4 and 6.5 until criterion end point was reached. The control group and runners did not improve their $+G_z$ tolerance and were significantly lower than the weight lifters. Data on changes in body fluids also show differences between groups, but apparently do not favor $+G_z$ tolerance. This latter finding is in contrast to a substantial body of work done on $+G_z$ tolerance at 3G in a passive mode following bed rest. The blood chemistries are not completed and are expected to add considerably to the elucidation of the general systemic adaptation involved. Again, the fact that $+G_z$ tolerance is related to the incorporation of significant muscle isometrics and respiratory maneuvers suggests that high intensity training may add resistance to the fatigue experienced by pilots of high speed aircraft. Further, it suggests that endurance training (moderate intensity, long duration) may habituate the baroreceptors and be counter-productive to the active mode of high $+G_z$ tolerance.

12. Fibrinolytic and Hemostatic Changes during and after Maximal Exercise

This study was designed to investigate the effects of age and fitness on the hemostatic mechanism. The hemostatic mechanism is centered to the clotting response. The predispostion for clotting is highly related to the condition of coronary infarcts and as such is a measure of cardiovascular fitness. This data set gathered over a wide age spectrum is central to the projected test battery being developed as a physiological profile to assess physical performance capabiliteis and limitations of Air Force personnel. The broader aspects of this work are contained in Dr. Gerald Davis' Ph.D. thesis cited in the bibliography attached. The acute exercise response is contained in a paper published in the Journal of Applied Physiology.

The age, fitness influence can be summarized as follows: 1) the predisposition to form clots increases with age, starting with the 20-to 30-year-age decade and continues through age 50 and 60. It decreases after this age. This is interpreted as a age-survival characteristic, i.e., those individuals surviving into their seventh decade have a lower predisposition for clotting; 2) physical conditioning significantly lowers the clotting predisposition associated with exercise throughout the age range of 20 to 60 years. The acute exercise response revealed that the primary increase in clotting potential occurred when the exercise intensity was greater than 80% of maximal. The increase in WBC, platelet count, and retention was observed at maximum exercise and proceeded progressively from rest to peak at maximum exercise. The study emphasized the use of exercise testing to elucidate this critical response.

13. The Role of Neurogenic Factors in the Regulation of Respiration during Sinusoidal Workload in Man (A completed M.A. Thesis and paper submitted for publication)

This study is a direct outgrowth of the development of the on-line data acquisition system. It represents the culmination of basic developmental work by a team of computer, exercise, and physiology specialists. It is important in the context of demonstrating the expanded potential to pose problems of a theoretical nature, involving the human model in a non-invasive mode. The applied question is relevant for it involves one of the limiting systems to sustained high intensity $+G_z$, viz., the respiratory system.

The input driving respiration during increased workloads is not completely understood. The debate between neurogenic and chemogenic forcing functions continues to hold forth, but convincing evidence is lacking. The capability of varying workloads in a dynamic mode sinusoidally showed that ventilatory response to exercise is influenced by the degree of proprioceptor activity in the working limbs. The persistence of this response throughout sinusoidal exercise indicates that the proprioceptors do not play a trivial role.

14. Combined Effects of Breathing Resistance and Hyperoxia on Aerobic Work Tolerance

This investigation studies the effects of inspiratory resistance on aerobic work tolerance. The paper has been accepted for publication in the Journal of Applied Physiology. Since the pilot is working against high resistance during $+G_z$ acceleration, it was of some interest to us to determine the effects on his aerobic and anaerobic capacity.

In general, it was found not to change his submaximal $O_2$ intake or anaerobic threshold. However, if the work becomes maximal, i.e., above 85%, there were significant reductions in his ventilation, $O_2$ uptake, and endurance. Sudden reduction in resistance or breathing hyperoxia mixture permitted work to continue.

15. Exercise Performance in 6 to 11 Year Old Boys with Duchenne Dystrophy

This study was made possible by the development of the data-acquisition system. The problem, although clinical, has important ramifications with respect to oxygen utilization by the peripheral tissue, principally muscle tissue. The delivery and utilization of oxygen is central to a number of physical stressor conditions experienced by pilots flying high speed aircraft. *Dystrophy is a metabolic disease of muscle* tissue and consequently can serve as a model to test the limitations of the oxygen utilization of muscle limited either by capillary flow, diffusion, or the metabolic capacity of the three principal types of muscle fibers or motor units. To date no standardized quantitative metabolic measurements have been developed to test the progressive deconditioning of this disease. Dystrophic boys were matched to normal boys on the basis of age, height, and weight. At rest, the dystrophics had higher heart rates, lower stroke volume, with no difference in $O_2$-uptake, cardiac output or pulmonary ventilation. During submaximal work, oxygen uptake, stroke volume, cardiac output and ventilation were lower in the dystrophic. Maximal work responses were all significantly lower. It was concluded that Duchenne muscular dystrophy, even in its early stages, apparently affects the work capacity of cardiac and pulmonary muscles as well as limb muscles and poses further elucidation of the histochemical changes associated with physical condition and metabolic capacities. This work is contained in thesis form and has been accepted for publication in the Journal of Physical Medicine and Rehabilitation.

## C. Development of Cooperative Arrangements with Other Air Force Related Institutions

1. Collaborative Studies with USAFA

Several studies have been conducted involving USAFA and UC Davis personnel. Two such studies have involved summer testing programs at USAFA, with the cooperation of USAFA personnel from the departments of Physiology and Physical Education. The first results of

these studies has been reported in the literature (Adams, et al, 19 ). The second was part of a longitudinal data collection program which is now being continued throughout the academic stay of the cadets tested. The first tests were described in the annual summary report for 1974-75; data collected in the second phase of the investigations are now being prepared for analysis.

A major factor in these latter investigations has been the support of USAFA testing processes by computer equipment provided by UC Davis. In the 1975 experiments, a computer system was driven to the Academy where dual testing stations were used during the period July and August, and then the equipment was returned to Davis (following use at Nellis AFB, described below). In May 1976, the same equipment was once again installed at the Academy, but this time is was left there for further studies after the programmed annual followup had been completed. It has been used periodically since that time. In addition, technical staff at UCD are constructing a system based on a microprocessor for permanent installation at the Academy, with delivery scheduled for early 1977.

A number of computer programs have also been delivered to the computer center at USAFA, since their central computer used for teaching and research at USAFA is the same model and make as the central UC Davis campus computer. These programs are separately described elsewhere in this report.

UC Davis personnel have served in advisory capacities for a number of related experiments in physiological investigations, impact of admitting women cadets to the academy, and computer-related topics over the past five years. They continue to serve in this capacity, and are optimistic about long-term associations in scientific collaboration.

2. Collaborative Studies with School of Aerospace Medicine, Brooks AFB

There have been a number of studies conducted jointly with representatives of AMD and SAM, Brooks AFB. Among them are the investigations of models describing dynamic responses to acceleration, reported in annual meeting summaries and also in several articles (Miller and Green, Green and Miller). These investigations opened the door to a number of related studies, some of them conducted at Brooks and others at AMRL in Wright Patterson AFB, Dayton.

A recent collaborative study on the effects of different types of conditioning programs on $G_z$ tolerance is now in final stages of analysis. This investigation, which was conducted at Brooks using AF personnel as subjects, demonstrated the relative improvement in performance of subjects conditioned through a weight-lifting program in comparison with others using running and control groups. The study was noteworthy in its demonstration of the feasibility of such types of cooperative research as well as the significant physiological results that raise interesting new questions about basic tolerance and conditioning for Air Force related tasks.

Other studies conducted through this contract related to suggestions for data collection techniques and data analysis. Although preliminary efforts of this type have been undertaken, no permanent results can be documented at this time.

3. Collaborative Studies with Aerospace Medical Research Laboratories, Wright Patterson AFB

a. Bibliographic System. The bibliographic sorting and selection system developed at Davis was transferred to Wright Patterson computer facilities, where it is believed to be in use in a variety of different bibliographic applications. Because of the program's unique approach to identifying numeric range data within the indexing system it is highly appropriate for indexing reprints and key articles in specific areas of research, and for that reason it has been adopted by a number of different groups.

b. Human Performance Models. A separate contract for the investigation of models of human performance under dynamically changing conditions relied on the consultation provided by one of the Davis faculty, Dr. Jerry Green, whose work with Dr. Nicholas Miller in developing a model for dynamic responses to acceleration is described elsewhere in this report. The detailed study of various available models treated the Miller-Green model as one of the key approaches to this field and their report represents a significant area of cooperative investigation which could be pursued in greater detail if time and funds are available.

Another area of cooperative work in human performance modeling has been the installation at AMRL of the Human Performance model developed through this project. This installation required conversion of the model for a different computer, which was done at the University of Indiana (see below) based on the documentation and machine readable code delivered to Indiana from Davis and on subsequent discussions and correspondence on technical points. The model is now available to researchers at AMRL, and it is receiving some critical evaluation at the present time.

c. Thermography. A number of detailed studies on techniques for recording skin surface temperatures have been jointly investigated by UCD and AMRL personnel. In 1974, equipment was flown from Dayton, Ohio to Davis, and a significant number of special investigations were undertaken with this equipment to evaluated its effectiveness and its relation to other measurement techniques. Detailed analysis of this data has continued since that time, with a report in final stages of preparation on one aspect and a second report submitted for publication. Plans are now being developed for the extension of this approach to thermography, and a new proposal is under development to support this research. In addition, cooperative arrangements for follow-on studies are also being explored within existing available funds.

d. Cooperative Development of Computer-Based Approaches to Data Analysis. A number of projects have arisen during the period of the contract relating to the use of computers in collection and analysis of data. The Human Performance Laboratory at Davis has been visited often by representatives of AMRL, and similarly, UC Davis personnel have on several occasions visited Wright Patterson to discuss areas of development of programs. The new project involving delivery of a microprocessor-based computer system to USAFA led to exploration of similar contract types of developments for AMRL. Although no final results on this phase of the project have been agreed upon as yet, the potential for utilizing expertise at Davis is under consideration, and some preliminary contacts have been made.

4. Collaborative Studies with AFOSR-Sponsored Research Institutions

a. University of Kentucky. Researchers from Davis have visited the University of Kentucky on several separate occasions during the contract period to assist them in the installation and use of their data acquisition systems. Assistance included design and creation of some special purpose peripherals, installation of software developed at Davis for the Raytheon computer, consultation as to interface requirements for different systems available at Kentucky, and advice on formatting data for analysis. In addition, long distance telephone communication links were used to access the interactive data storage and analysis package at Davis in the study of key data obtained in experiments at Kentucky. Assistance in entering these data into the UC Davis system was a significant element in this cooperation.

b. University of Indiana. The University of Indiana's research on thermoregulatory mechanisms in non-human primates complements in many ways research on human subjects at Davis. Because of the potential for acquisition of key data through invasive techniques not feasible withhumans, the researchers at Indiana proposed that collaborative research be undertaken involving adaptation of the performance model for representation of rhesus monkey thermoregulatory control mechanisms. This conversion was performed at Indiana, copies of the program were sent to AMRL, and a listing together with the revised documentation is availalbe at Davis for exportation elsewhere.

c. University of California, Santa Barbara. UC Davis researchers have benefitted greatly from the biochemical assay techniques developed at Santa Barbara, and they have visited the Santa Barbara campus on several occasions to learn more about these techniques, their pitfalls and limitations as well as their potential. In addition, personnel from Santa Barbara have on several occasions visited Davis to discuss specific research projects of mutual interest and to evaluate data collection and analysis techniques at Davis.

d. Mayo Clinic. Prior to the 1973 review held at the Air Force Academy, an offer was made to participants to submit data to UC Davis for incorporation into an interactive data analysis package (the earlier version of the system now available). Mayo Clinic researchers responded by sending a set of data which they were then able to analyze while at the meetings. The potential for further studies of this sort were explored but never followed up.

e. University of California, Los Angeles. The use of remote telemetry for physiological experiments was developed a number of years ago by Dr. Ross Adey and his co-workers at UCLA. Davis researchers have benefitted from this research in a number of ways, duplicating some of the approaches to remote investigations. In return, we have described to the UCLA group our results in control of the computer system from the remote site, a minor modification made possible by the collaborative research between the two institutions.

5. Investigations Involving Air Force Personnel on Active Duty

A number of problems of basic importance to Air Force tasks can be studied best by analyzing the personnel involved. Fighter pilots, for example, may or may not exhibit different states of conditioning, tolerance to certain physiological stresses and potential for improvement; the answers to these questions almost necessarily presuppose that these personnel must themselves be studies. One of the major goals of this contract has been to develop methods whereby such studies can be undertaken without jeapordizing the responsibilities of these personnel nor interfering with other activities at Air Force bases. The studies conducted at Nellis AFB in 1975 and at Brooks in 1976 represent major significant breakthroughs in the study of Air Force personnel by civilian research groups. A great deal of the credit for arranging these investigations is due to Col. Wisecup at AFOSR; the techniques utilized were the responsibility of Davis researchers, who developed mobile testing equipment that could be taken to Nellis for use during a concentrated period of time at that location. These techniques, which were also used in the collaborative studies with the Academy, proved highly successful in practice, though selection of appropriate groups of test personnel was not in every case optimal for the questions being posed. Having established the feasibility and methodology for such investigations, however, it now appears possible to consider future investigations in which university-based researchers may be able to study combat personnel in situations necessary for the elucidation of basic questions in stress responses and tolerance.

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Operating Instructions, Raytheon Instrumentation Package. L.W. Harter, 1972.

TSCSMP: Timeshared Continuous Systems Modeling Program. J.C. Wilcox, 1973.

DSAP: Preliminary Manual. J. C. Wilcox and R. F. Walters, 1973.

HPMOD Human Performance Model: User's Manual. N.C. Miller and R.F. Walters, 1972.

Raytheon System Support Routines. R.W. Schultz, 1972.

DSAP (Data Storage and Analysis Package). Final Documentation, A.R. Werback, J.C. Wilcox and R.F. Walters, 1976.

Raytheon Source Documentation. A.R. Werback, 1975.

Introduction to the Raytheon Computer. A.R. Werback, R.F. Walters, 1975.

GENPLOT: General Purpose Plotting Routine. J.C. Wilcox, 1972.

SEARCH Manual: for operating Bibliographic Searching and Selecting System. J.C. Wilcox, 1973.

SAM: A microcomputer-based Data Acquisition System. A.R. Werback, L.W. Harter, R.F. Walters (in preparation).

Note: The computer programs, manuals, and instrumentation developed through this grant are available in the public domain for anyone desiring copies. Multiple copies of several items, notably the human performance manual and bibliographic system have been sent to date. Schematics on instrumentation is also available upon request. Copies will be furnished to AFOSR if requested, or individuals may contact the Principal Investigator (R.F. Walters) at (916)-752-3241.

COMPUTER PROGRAM

Laboratory Data Acquisition System (Raytheon)

On-line Data Acquisition Support for Max $VO_2$ Treadmill Experiments

(Including calibration, pre-test data entry, on-line acquisition, post-test data verification, and data reduction)

On-line Data Acquisition for Sinusoidal Workload Experiments

(Including calibration, forcing function control of bicycle/treadmill data storage during experiment and initial data reduction)

Remote Data Entry from Experiments

(Including communications interface for telemetry data, remote computer console modification and adaptation of on-line data acquisition programs)

Systems Utility Software

(Including diagnostic routines, memory management for tape files, mathematic functions, I/O support, several enhancements over Raytheon-supplied system, source file management routines, library-to-tape dump routines, etc.)

Remote Magnetic Card Data Entry

(Including communications interface for IBM BCD code)

Communications Interface to Central Campus Computer

Ramp and Interrupt-Driven Respiratory Volume Data Acquisition System

Calibration Routines (2 separate systems) for Calibration of Gas Analyzers Used in Experiments

Laboratory Data Acquisition System (Microprocessor)

System Utility Routines

(Including memory diagnostic, operating systems modification, mathematics package, I/O interface to video and printer devices, communications interface to central computer, I/O formatting package, etc.)

Data Acquisition Package (not yet completed)

Central Campus Computing Facility

Bibliographic Support and Selection System

Revised to run on B6700. Includes interactive and batch retrieval, batch filer.

CSMP (Continuous Systems Modeling Program):

Modified to run on B6700. Interactive Version also implemented

HPMOD: Predictive Model of Human Performance

DSAP: Data Storage and Analysis Package

Revised two times during contract period to enhance selective retrieval /display/analysis options

MUMPS Interpreter:

Experimental work done to assess validity of interpreter on B6700 hardware

Cross Assembler: Microprocessor System

Hardware Manufactured or Modified

Controller for Treadmill (speed as well as elevation)

Controller for Bicycle Ergometer

Communications Controller

Interface to IRIG Telemetry Channels

Disk Modification to Permit Lockout of Program Storage Area

Interface of New Memory (Fabritek)

Interface and signal conditioning (hardware) of various laboratory devices, including MedSpect $O_2$-$CO_2$ analyzer, R-wave detector, pneumotachometer, Parkinson-Cowan volume meter, ECG, temperature transducers.

Modification of Parkinson-Cowan volume meter to produce tenth-liter interrupts

Development of R-wave detectors, improving on NASA design

Reconditioning of alternate Raytheon 703 computer for local and remote use

Modification of system to permit remote console control of system

Development of microprocessor-based data acquisition system (still under development)

Development of battery-powered telemetry unit (not yet complete)

Interface of Digital Plotter (Calcomp) to laboratory system

Interface of Graphics terminal (storage tube)

Special Services to Other Institutions

Bibliographic Indexes mailed regularly until service discontinue in 1973 to:

AMRL, SAM, USAFA, NASA/Houston, University of Kentucky, AFOSR.

Individually requested searches for data performed on request from beginning of contract through August, 1976.

Delivery of Bibliographic Programming System to Outside Institutions

To date the $BS^3$ System has been sent in machine readable form to at least a half-dozen institutions in the United States and Europe, including the computer center at AMRL, Wright Patterson AFB, USAFA, and Lawrence Laboratories (Livermore).

Human Performance Model:

Delivery of manual, code and assistance in conversion to other systems has been a major element of the project. To date the model has been sent to over fifteen institutions in the United States and Canada, including AMRL (Wright Patterson), NASA/Houston, USAFA, the University of Indiana, the Pierce Institute, U.S. Army Research facility at Natick, Mass, and numerous universities and colleges.

Data Storage and Analysis Package

Delivered together with preliminary documentation, to USAFA. Revised documentation is being prepared for delivery during current grant year. System was used for demonstration data analysis using University of Kentucky and Mayo Clinic data at USAFA conference, 1973.

# APPENDIX

AFOSR 72C-0011

Progress Report
on
Measurement of Skin Temperature in Man
in Varied Activity Modes and Ambient Conditions

During exercise, the metabolic heat produced increases considerably over that at rest, and unless all this heat is eliminated the body temperature will rise. Furthermore, in hot ambient conditions, air temperature may be higher than the skin temperature. In such conditions, not only must all the heat of metabolism be lost by sweating, but also additional sweat must be evaporated to remove heat absorbed from the air by convection. Likewise, in sunny conditions relatively large amounts of heat absorbed from solar radiation must be dissipated. In any case, one must measure the skin temperature in order to calculate the magnitude of heat exchange through the various avenues.

It has been shown in numerous laboratory experiments that skin temperature is a function of the ambient temperature and is little affected by work intensity. However, the effect of exercise mode, as well as the potentially modifying influence of humidity, air flow and radiation on mean skin temperature has not been investigated systematically.

It is our intention to measure skin temperature at numerous sites in several activity modes during exposure to varied ambient conditions. Specifically, six young, male subjects (ranging from non-trained to highly trained) will exercise indoors at two work rates on a bicycle ergometer and treadmill at airflows varying from 0-10 mph in ambient temperatures varying from 65-95°F. Using a motorized light utility van equipped as a mobile research unit, respiratory metabolism, core and skin temperatures will be measured at rest and during exercise while the subjects are exposed to widely varied ambient conditions with respect to temperature, humidity, airflow and solar radiation level.

Since we had determined in previous work that skin temperatures measured by thermistors taped to the skin do not agree with infrared thermovision values we have abandoned their use. Recently, we have found that thermistors lightly held to the skin surface by a plastic ring and surgical tape are a more accurate method of assessing mean skin temperature. However, there are situations in which direct continuous measurement of skin temperature is not feasible. Thus, it was our intention to examine the validity of the immediate post-exercise recovery estimation technique. The method to be utilized involves taking readings at 6-8 sites on the body surface, a set of readings being completed 2-3:00 after cessation of exercise. On other occasions the rate of rise after exercise is measured by taking serial readings over a single site, and extrapolating back to cessation of exercise, time zero.

Recently, the effects of forced convection and solar radiation on the ambient dry bulb, mean skin temperature relationship were studied in three distance runners while running and cycling. Seven skin temperatures and rectal temperature were monitored sequentially at 3-4 sec intervals each minute during treadmill runs of 11.1 km at 254 and 293 m/min in cool, moderate and warm $T_{db}$, with and without airflow equivalent to the runner's speed, and for 3 min postexercise.

It was found that the linear extrapolation of the mean of the first three recovery skin temperature measurements at each site back to time zero rarely

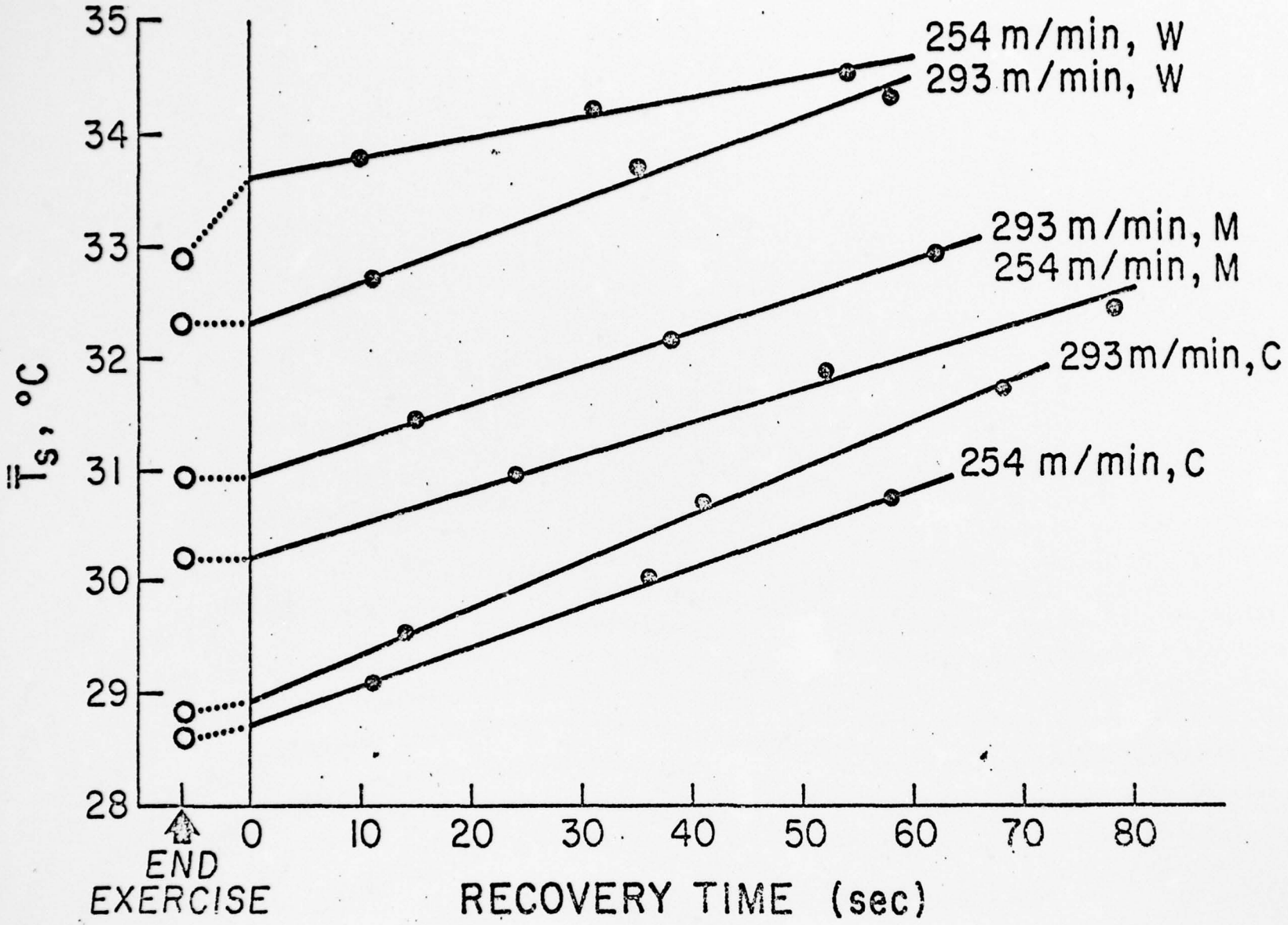
deviated more than ± 0.2°C from the measured mean skin temperature during the last minute of indoor runs with airflow equivalent to running speed (see Fig. 1). Similarly close approximations were also observed following indoor runs without airflow. Another major finding was that the measured last minute mean skin, dry bulb temperature relationship for indoor runs, with airflow, did not differ significantly from the extrapolated end-run mean skin, dry bulb temperature relationships obtained for the outdoor runs, postsunset. Thus, the indoor, with airflow, treadmill runs appear to be an acceptable simulation for study of heat exchange during outdoor running without direct solar radiation. The calculated least squares regression line for individual observations in these two conditions (shown as darkened symbols) is given in Figure 2. Also depicted are values obtained in the last minute of indoor runs without airflow (seen as open squares), and extrapolated end-exercise values for outdoor runs in clear sky solar radiation (seen as open circles), and for bicycle rides in clear sky solar radiation and postsunset (seen as open and darkened triangles). It is readily apparent that the mean skin, dry bulb temperature relationship for indoor treadmill running with airflow equivalent to the runner's speed was not significantly different from that for outdoor running, postsunset, whereas that for indoor runs in "still" air and outdoors in clear sky solar radiation were. Furthermore, the importance of forced convection on the mean skin, dry bulb temperature relationship was further demonstrated by a significantly lower mean skin temperature when bicycling outdoors at a metabolic rate nearly equivalent to running outdoors at similar dry bulb temperature.

In 20 experiments, pre- and postrun, near steady-state telethermometer values were compared to those obtained by a Barnes infrared radiometer at sites closely adjacent to the thermistor sites. The mean skin temperature obtained by telethermometer readings was approximately 1°C lower than the mean skin temperatures measured by radiometer, while there was no significant difference between the two techniques in measurements taken from 3-4 min postrun. These discrepancies deserve consideration of further study, perhaps with AGA thermovision in collaboration with Dr. James Veghte, Wright Patterson AFB.

Furthermore, as seen in Figure 3, when evaporative and convective cooling are restricted, mean skin temperature drops initially and then rises progressively at a rate partially dependent on exercise intensity. Thus, extrapolated recovery measurements outdoors in high humidity would reflect only the end-run skin temperature. Development of biotelemetry capability has advantages over the present system with the thermistor leads coupled to a telethermometer carried in a vehicle moving alongside the exercising subject. Some progress has been made in developing a biotelemetry capability, but technical difficulties have prevented its fruition to an operational stage.

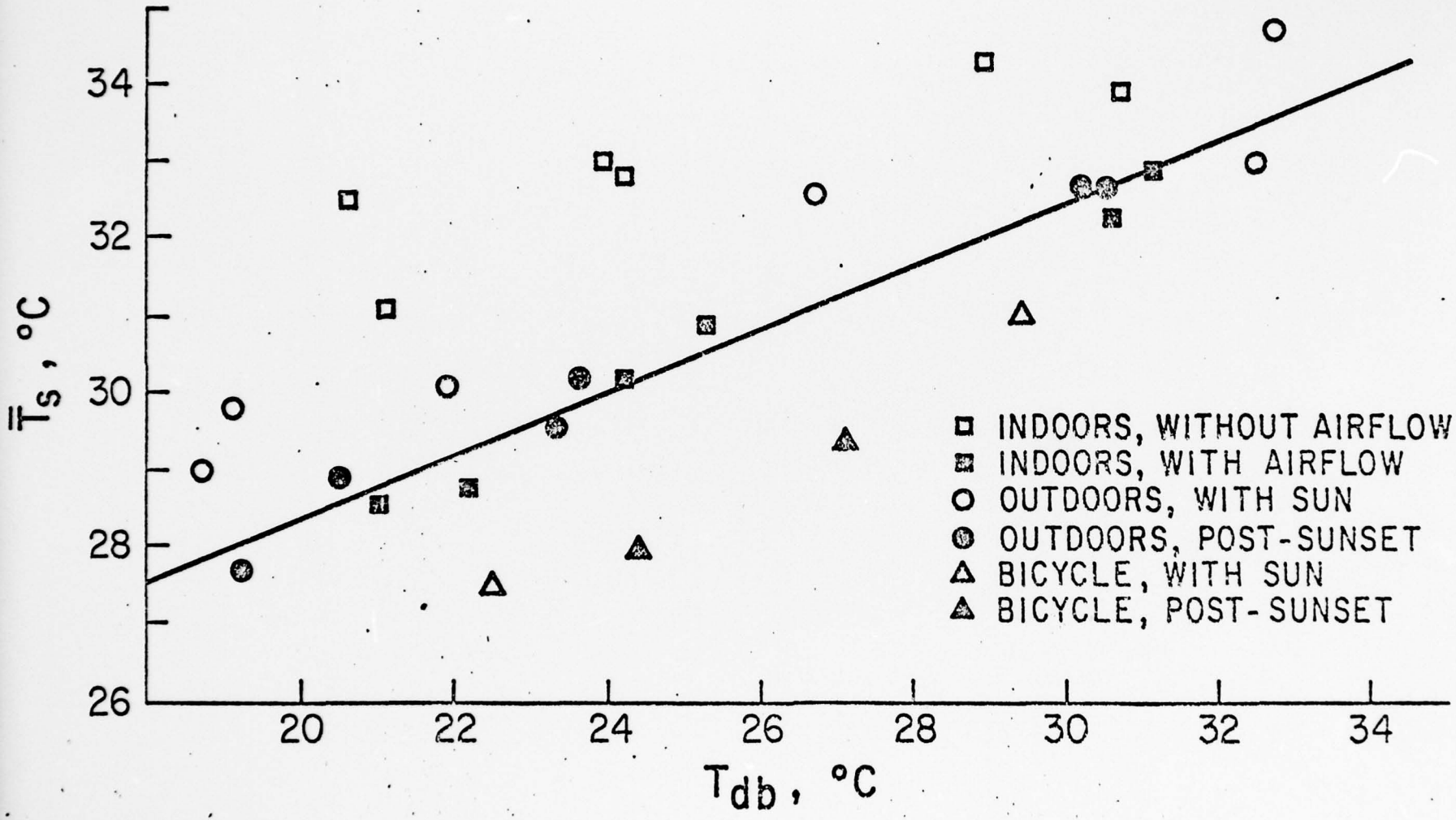
It is also anticipated that measurement of skin and rectal temperatures of subjects exercising indoors can be made computer compatible for greater precision, data analysis advantages and ease of data storage. Addition of this data input to the respiratory metabolic data already available will add significantly to our capability for identifying limiting factors in physical performance.

FIGURE 1



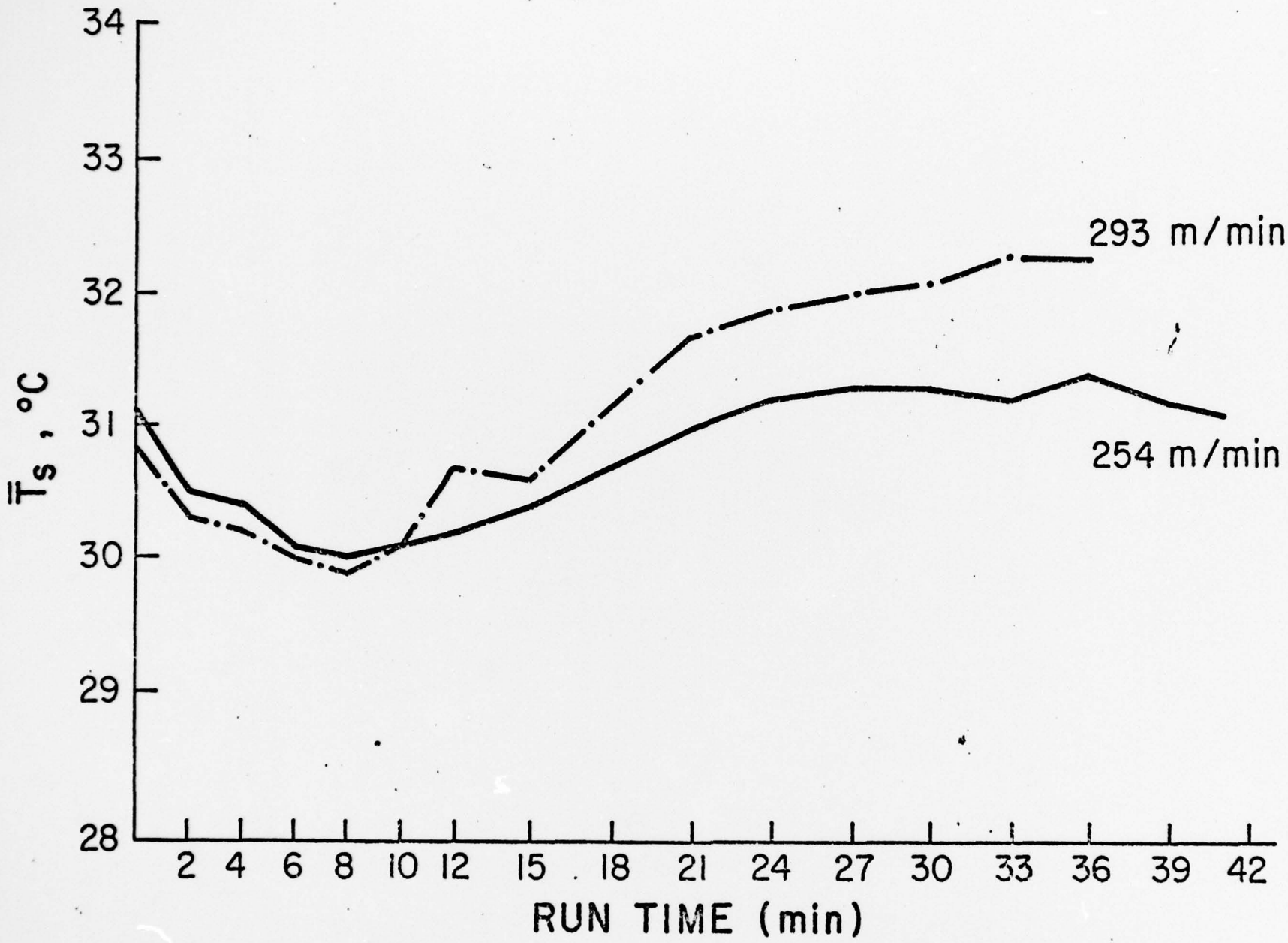

LINEAR EXTRAPOLATION ESTIMATE OF END-RUN $\bar{T}_s$ FROM RECOVERY $T_s$ MEASUREMENTS.

FIGURE 2




END-EXERCISE $\bar{T}_s$ AS A FUNCTION OF $T_{db}$ FOR SUBJECT 1.

FIGURE 3




MEAN SKIN TEMPERATURE DURING TREADMILL RUNNING AT TWO SPEEDS IN C TEMPERATURE WITHOUT AIRFLOW.